USAAVRADCOM-TM-80-D-7

ADA086857

(12)

LEVEL II

INVESTIGATION OF HELICOPTER WIRE STRIKE PROTECTION CONCEPTS

LeRoy T. Burrows

June 1980

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REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER USAAVRADCOM-TM-80-D-7 — 2. GOVT ACCESSION NO. AD-A086857	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) INVESTIGATION OF HELICOPTER WIRE STRIKE PROTECTION CONCEPTS	5. TYPE OF REPORT & PERIOD COVERED Technical Memorandum Aug[redacted]— Nov[redacted]1979
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) LeRoy T. Burrows	8. CONTRACT OR GRANT NUMBER(s) House Task 79-16
9. PERFORMING ORGANIZATION NAME AND ADDRESS Applied Technology Laboratory, U. S. Army Research and Technology Laboratories (AVRADCOM) Fort Eustis, Virginia 23604	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L162209AH76
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE Jun[redacted]80
	13. NUMBER OF PAGES 51
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 52	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Helicopters	Protective Equipment	Impact Tests
Cable Cutting Devices	Retrofitting	Test Methods
Cables	Aviation Accidents	
Wire	Aviation Safety	
Cutters	Low Altitude	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In-flight wire strikes pose a serious threat to low-level helicopter operations. Tests were conducted to determine the suitability for U. S. Army helicopter applications of the Canadian Wire Strike Protection System (WSPS), developed by Bristol Aerospace Limited. The WSPS consists of fuselage-mounted upper and lower cutters and a windshield centerpost deflector with a sawtooth cutter.

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Block 20. Abstract - continued.

Using the NASA/Langley Research Center Crash Impact Dynamics Facility, an OH-58A fitted with the WSPS was subjected to pendulum swing tests in which the helicopter struck fixed cables at approximately 40 knots airspeed. The system demonstrated the capability to easily sever 10,000-pound-strength 3/8-inch steel messenger cable, 50-pair copper communications cable, and 0.419-inch high-power transmission lines, including multiple arrays of those cables. Data acquired indicated that the wire impact/deflection/cutting sequence would not have a significant effect on helicopter performance, control, crew functioning, or blade flapping. Installation of the WSPS on the entire Army tactical helicopter fleet is recommended.

An additional test of a device to deflect wires past the helicopter skid gear, vertical stabilizer, and tail rotor was conducted. A 7/8-inch tubular steel deflector was designed and fabricated. The device proved to be inadequate. It was concluded that a skid gear deflector is not a practical OH-58A retrofit from a cost and weight standpoint.

PREFACE

The project engineer for the tests described herein was LeRoy T. Burrows, Aerospace Engineer, Safety and Survivability Technical Area, Aeronautical Systems Division, Applied Technology Laboratory (ATL). Other contributing ATL personnel were Mr. Paul Triplett, lead Aerospace Technician; Mr. John Chappell, Instrumentation Engineer; and Mr. Dominic Ianuzzi, Instrumentation Technician.

The author extends his gratitude to the following organizations and individuals for the support specified:

- NASA-Langley Research Center (LRC) for facility support, conducting the pendulum swings of the aircraft, and external photography. Dr. Robert Thomson, Mr. Claude Castle, and Mr. Dwight McSmith, all of the LRC, were instrumental in the success of these tests.

- U. S. Army Transportation School, Department of Aviation Systems, for loan of the test vehicle and for conducting the weight and balance measurement of this aircraft.

- U. S. Army Transportation Center and Fort Eustis Directorate of Facilities Engineering, Utilities Division, Electrical Branch, and the U. S. Army Communications Command Detachment, Fort Eustis, for erecting the wires for these tests.

- ATL Technical Services Division for test preparation; principally Messrs. Edwards, Krowe, and Doxey.

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INTRODUCTION

In-flight wire strikes are a serious threat during all-weather daytime and nighttime helicopter operations, including:

- Terrain flight (nap-of-the-earth, low-level, and contour flight)
- Enclosed area takeoff and landing
- Confined area maneuver

The U. S. Army's growing emphasis on these operations is a major reason for the recent increase in wire strikes experienced. Despite concentrated training on avoiding wire strikes and actions such as mapping of wires in training areas, removal of unnecessary wires, marking of cables with orange spheres or other devices, and preparation of SOP's to increase pilot awareness of the wire strike threat, the peacetime wire strike problem remains a serious one. During the period 1 January 1974 to 1 January 1980, wire strikes accounted for 8 percent of total Army aircraft damage, 6 percent of all Army aircraft injuries, and 16 percent of Army aviation fatalities. Inasmuch as many of these mishaps have occurred during training over familiar sites, it can be assumed that the wire impact threat posed by combat operations in unfamiliar areas would result in increased wire strikes. Furthermore, in a hostile environment the enemy can be expected to string wires as an intrusion countermeasure.

Since the emphasized operations require flight close to the ground during varying degrees of visibility, the hazards presented by wires and other obstacles cannot be eliminated. However, these hazards can be effectively reduced by configuring the helicopter system to be more tolerant of them. Increasing helicopter survivability to the wire strike threat will result in fewer mishaps, and therefore, increased aircraft availability, decreased maintenance, reduced casualties, and improved mission effectiveness.

A simple, cost-effective design approach to providing protection from the wire strike threat is a helicopter Wire Strike Protection System (WSPS) designed by Bristol Aerospace Limited (BAL) under contract to the Canadian National Defence Headquarters. This system consists of an upper cutter, a lower cutter, and a windshield centerpost deflector. An examination of electric power and telephone lines in use revealed that a steel, 3/8 inch diameter, seven-strand messenger cable with a tensile strength in excess of 10,000 pounds was the toughest cable found in abundance. It is designated as 10M cable by the industry. This type of cable had been the cause of many fatal helicopter accidents. Accordingly, the WSPS was designed to counter the threat of this cable, which was designated the design objective wire. The objective wire is used to support heavy communications cables that consist of many copper wires within, or to provide other structural support.

In May 1979, the Canadian WSPS was qualified for Canadian KIOWA helicopter (OH-58A) application. BAL conducted a series of 52 wire-cutting tests by mounting a deflector and upper cutter on a wrecked KIOWA fuselage, rigidly securing this to the flatbed of a truck, and driving the truck into fixed wires. Test variables included speed (15 to 60 mph), yaw angle (0 to 45 degrees), strike location (nose to top oi cutter), and wires (steel-reinforced aluminum cables, 10M, and guy cables). Concurrently, the Canadian Aerospace Engineering Test Establishment conducted a flying qualities and electromagnetic interference (EMI) qualification of the OH-58A with the WSPS installed. All wire cutting tests were successful and no significant effects upor. aircraft performance were noted.

TEST PROGRAM

The wire cutting test method employed by BAL validated upper cutter and deflector design objectives but did not test the lower cutter. The test also did not answer questions regarding aircraft pitch and yaw changes and deceleration loads during the wire impact and cutting sequence, and their potential effects upon aircraft control and blade flapping. To answer these questions, and thereby determine suitability of a WSPS for Army aircraft application, was the primary objective of the following ATL tests.

WIRE STRIKE PROTECTION SYSTEM EXPERIMENT

The primary purpose of this experiment was to determine the suitability of the Canadian WSPS for application to U. S. Army helicopters. This was to be accomplished by assessing the effect of single and multiple wire impact forces and the deflection/cutting sequence on aircraft control, the pilot, and blade flapping. In addition, the lower cutter was to be tested for structural integrity and wire-cutting capability. The upper cutter and deflector performance and structural integrity had been proven in tests conducted in Canada by Bristol Aerospace Limited.

SKID GEAR WIRE DEFLECTOR EXPERIMENT

The purpose of this experiment was to design, fabricate, and test a device that would deflect wires and cables past the skid gear, vertical stabilizer, and tail rotor, thereby protecting the helicopter from skid gear wire entanglement for all aircraft wire strike attitudes. With the WSPS it is possible for the wire to go under the lower cutter and be snagged by the skid gear, especially in the case of a nose-up attitude.

These tests were conducted in October 1979 at the NASA/Langley Research Center Crash Impact Dynamics Facility, Hampton, Virginia. The test vehicle was an Army OH-58A observation helicopter.

This report documents test preparation, description, results, and conclusions.

TEST FACILITY

The OH-58A Wire Strike Protection System test was performed at the Crash Impact Dynamics Research Facility shown in Figure 1. The basic structure of the facility is the 420-foot-high by 400 foot-long gantry. It is supported by three sets of inclined legs spread 267 feet apart at the ground level and 67 feet apart at the 218-foot level. A movable bridge spans the gantry at the 218-foot level and traverses the length of the gantry. A control room and an observation room are located in the building at the base of the gantry. Along the centerline of the gantry, at ground level, is a strip of reinforced concrete 400 feet long, 30 feet wide, and 0.67 foot thick.

The apparatus necessary to conduct a helicopter pendulum swing test is shown in Figure 2. Swing-cable pivot-point platforms, located at the west end of the gantry, supported the winches, sheaves, and pulley systems that controlled the length of the swing cables. A pullback platform, attached to the underside of the movable carriage, supported the winch, sheave, and pulley system that controlled the length of the pullback cable. Swing cables were attached to the helicopter rotor hub and, during the pendulum swing, supported the helicopter through the rotor mast, as it would be in free flight. A pullback cable with an electrically operated hook was attached to a specially fabricated fixture placed on the aft end of the tail boom.

Both swing and pullback cables could be varied in length to provide desired pendulum swing arc and velocity. For a wire height of 22 feet, the pullback position shown in Figure 2 was calculated to provide the desired wire impact velocity.

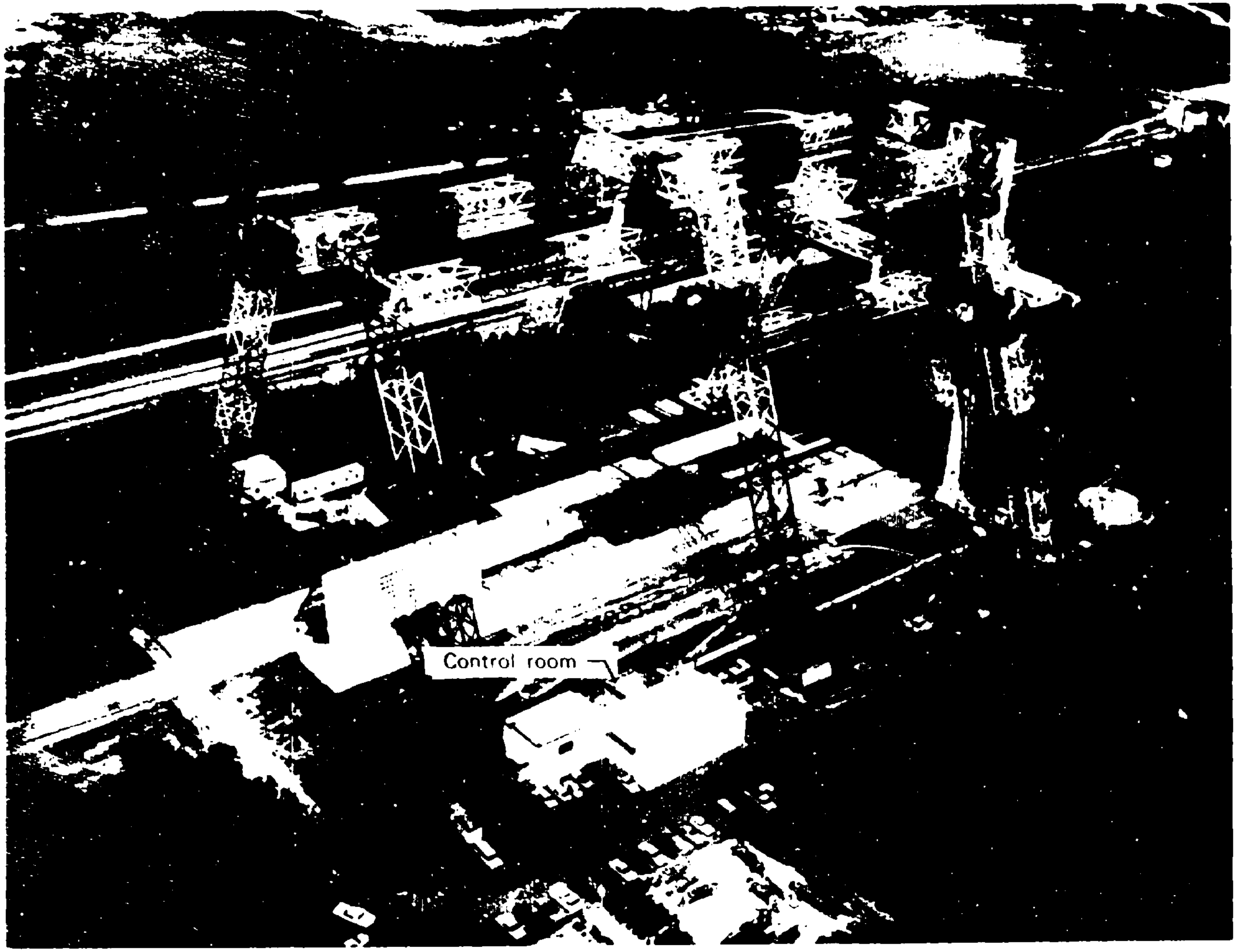

Figure 1. Langley Crash Impact Dynamics Research Facility.

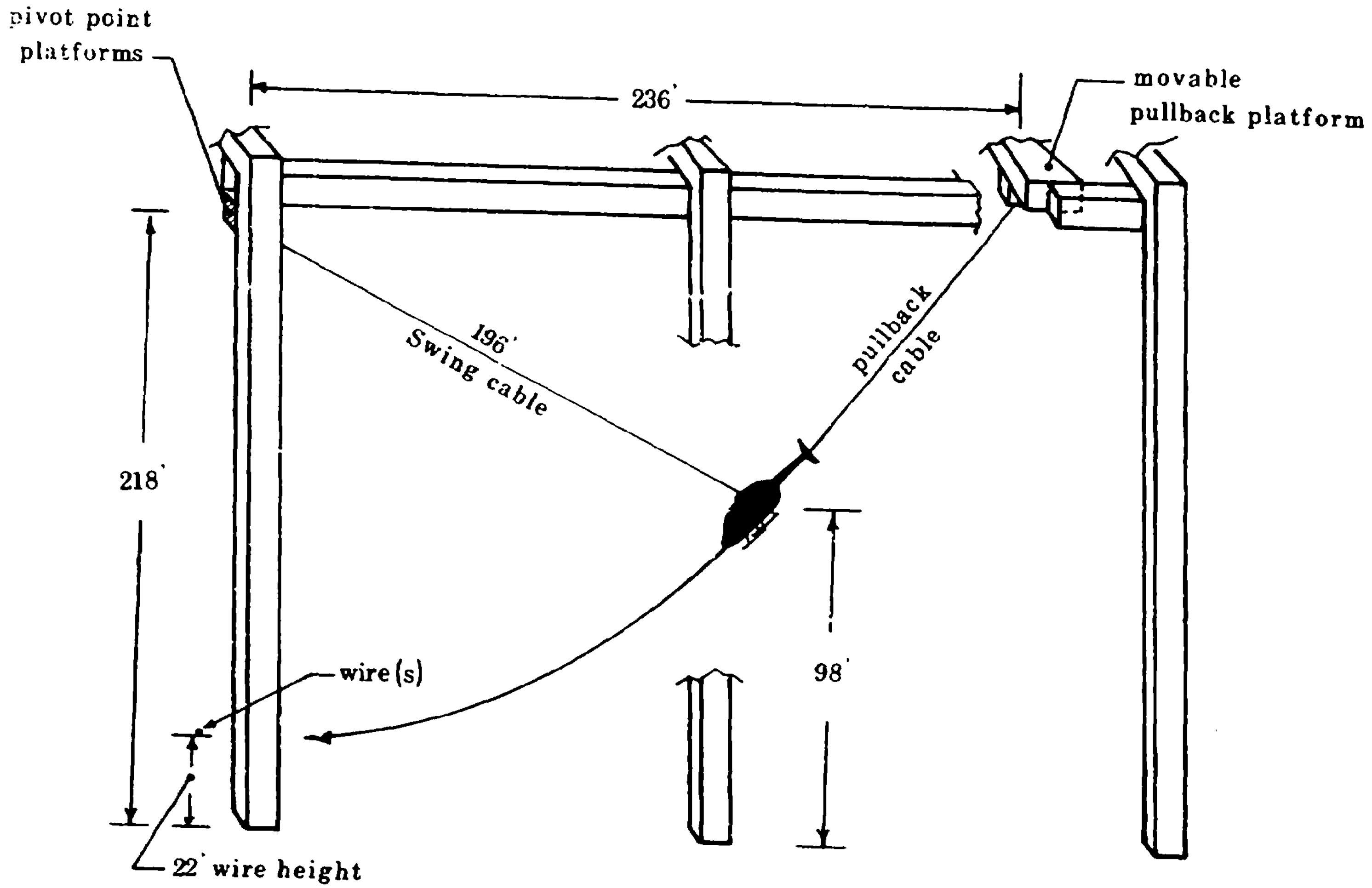

Figure 2. Pendulum swing test apparatus.

TEST SETUP

AIRCRAFT AND CUTTER/DEFLECTOR SYSTEMS

The test specimen was an OH-58A helicopter that had been retired from service and was being used for maintenance training by the U. S. Army Transportation School. It was fully equipped less avionic equipment. The aircraft was initially prepared for testing at the Applied Technology Laboratory. This preparation included installation of the Canadian OH-58A Helicopter Wire Strike Protection System and provisions for rapid installation of the skid gear deflector concept to be tested.

The Canadian WSPS is shown installed on the test aircraft in Figures 3, 4, and 5. This is a cutter/deflector system with an upper cutter to protect the main rotor controls; a lower cutter to protect the skid gear; and a windscreen centerpost deflector with a serrated cutting edge insert to deflect wires to the upper cutter, to cut copper and aluminum wires, and to reinforce the centerpost structure. The WSPS is a passive system, having no moving parts. Upon wire impact, the helicopter momentum deflects the wire or cable into the upper or lower wedge-shaped cutter, where it is notched to the extent required for easy breakage in tension. The total OH-58A WSPS weight is 16.3 pounds, including all supporting structure and the mounting plates. Installation of the WSPS required approximately 40 man-hours.

For the skid gear deflector the primary design consideration was weight, since that would dictate application practicality when compared to the WSPS lower cutter. Other design requirements established were:

- Sufficient strength to deflect a 1/2-inch cable impacted at 90 knots.
- Minium retrofit cost.
- Not a potential foreign object damage source.
- No interference with crew ingress, egress, or performance.
- Minimum modification to basic aircraft.
- Minimum drag addition to aircraft.
- No significant increase in aircraft susceptibility to snagging tree limbs or other objects during forward and lateral flight.
- Adaptable to vertical displacement of fuselage and horizontal displacement of skid gear during normal and hard landings.

Figure 3. WSPS upper cutter.

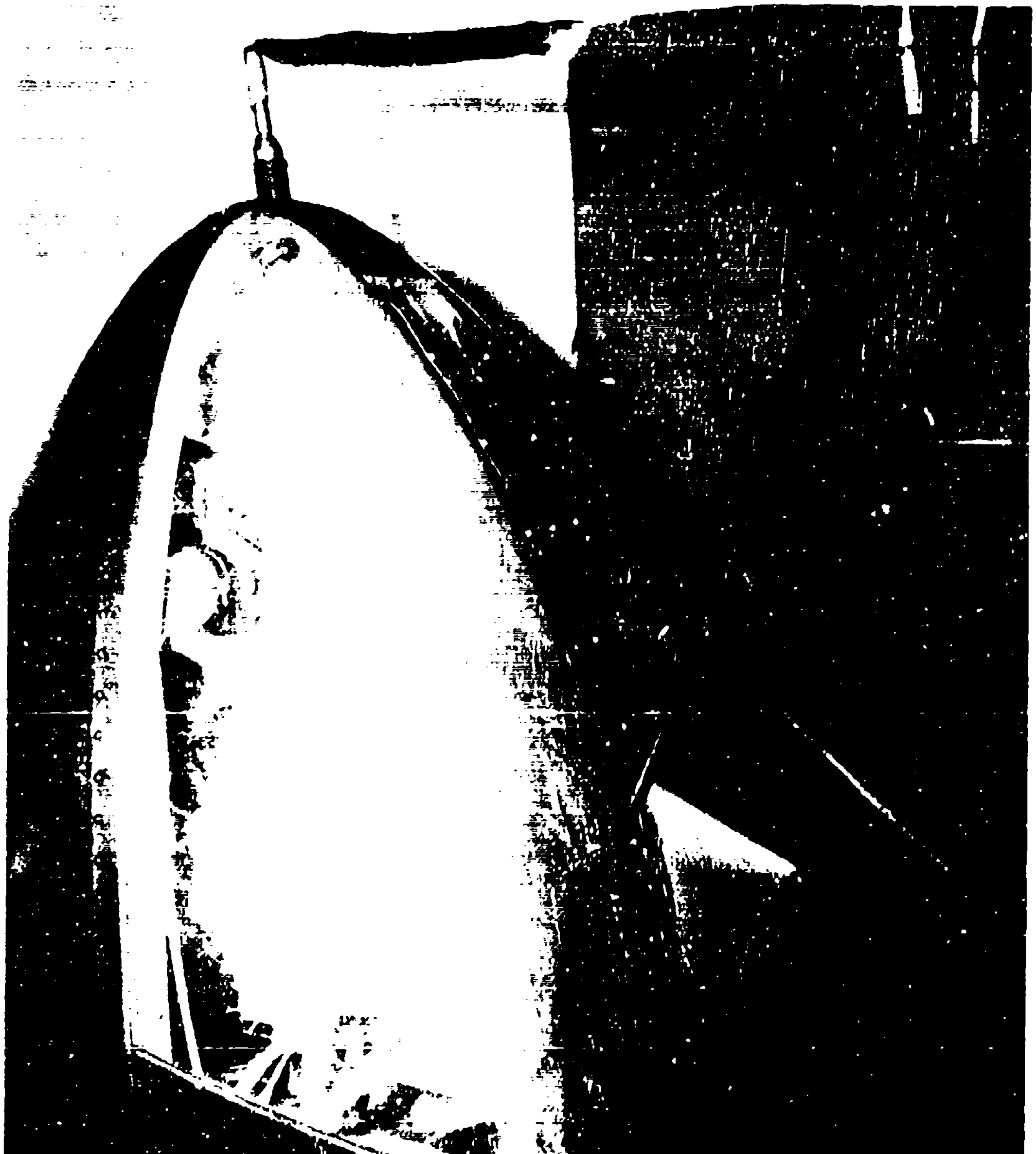

Figure 4. WSPS lower cutter.

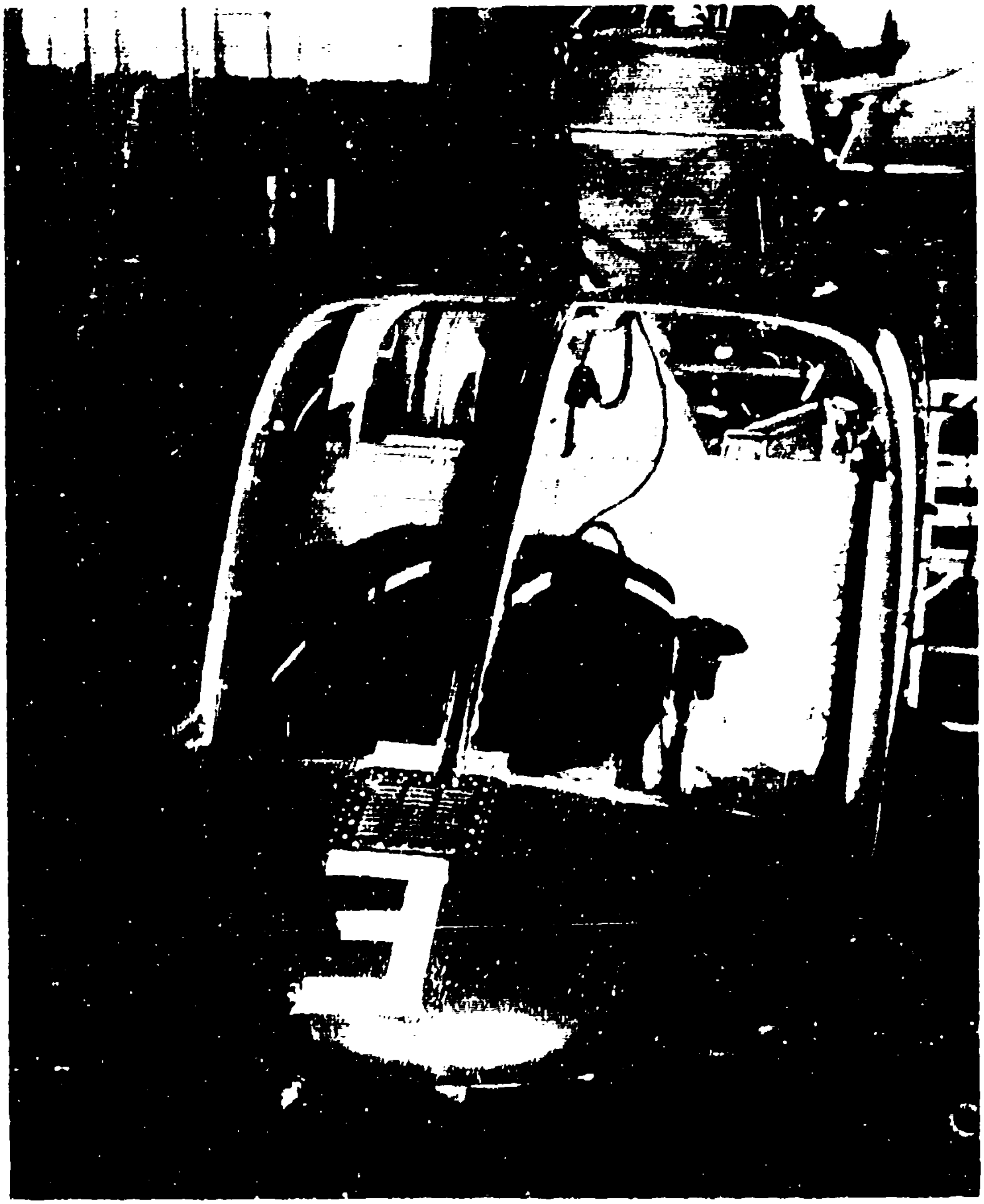

Figure 5. WSPS windshield centerpost deflector.

The design approach selected as a result of trade-off analyses was:

1. A one-piece tubular stainless steel deflector rod (7/8-inch OD, 3/16-inch wall thickness) that would provide a 45-degree angle of wire deflection and act as a natural spring during fuselage/skid gear deflections. The lower attachment was internal to the skid gear tube, resulting in a flush interface. The upper attachment to the fuselage was by a connector plate located just aft of the landing light (see Figures 6 and 7).

2. A deflector cable to provide vertical stabilizer and tail rotor protection (Figure 8).

A structural analysis of the selected design indicated that marginal performance could be expected. However, since the deflector concept chosen entailed an aircraft weight addition of approximately 17 pounds as compared to the 6.5 pounds for the WSPS lower cutter, it was decided that any additional weight increase would make the skid gear deflector concept impractical for application.

Additional aircraft preparation included provisions for the instrumentation package, fabrication and installation of an eyebolt connector for pullback cable hook attachment (Figure 9), camera mounts fabrication and installation, ballast installation, motion restraint fixtures for cockpit controls and rotor hub, and weight and balance calculations. Also, the main rotor blades were removed from the aircraft to prevent them from creating undesirable motion in the test vehicle during the pendulum swing. More than 900 pounds of ballast was placed in the aircraft to maintain a normal vertical cg, and to locate the longitudinal cg at the rotor mast station so as to decrease the possibility of erratic pitch motions of the aircraft during the swing prior to wire impact. The ballast weight was chosen to result in a typical mid-mission OH-58A gross weight of 2610 pounds.

Final test preparation at the test site included installation of the instrumentation package, umbilical cable connection, installation of batteries for sensor and camera power, check of each data channel, and camera installation and loading. All of the weight-related items were temporarily installed at ATL for the purpose of determining the weight and balance characteristics of the test helicopter.

OBJECTIVE WIRE

Communication/power line poles were erected at the test site 160 feet apart in a manner to permit stringing of the objective wires normal to the predicted aircraft flight path. The wires were strung approximately 15 feet forward of the swing-cable pivot-point platforms and at a height of 22 feet above ground level. This permitted raising and lowering of the aircraft to a pre-pullback position without wire interference. For the majority of tests the objective wires were a 10M steel, 3/8-inch diameter, seven-strand cable supporting a 50-pair communications cable of 0.85-inch diameter, containing 100 copper wires. Army line crews from Fort Eustis erected the wires in accordance with their standard procedures.

Use of a 160-foot objective wire strung at a standard height and tensioned by the line crew in accordance with normal procedures provided a realistic wire-cutting test and allowed a valid assessment of the wire free-end movement after it had been cut. Bristol

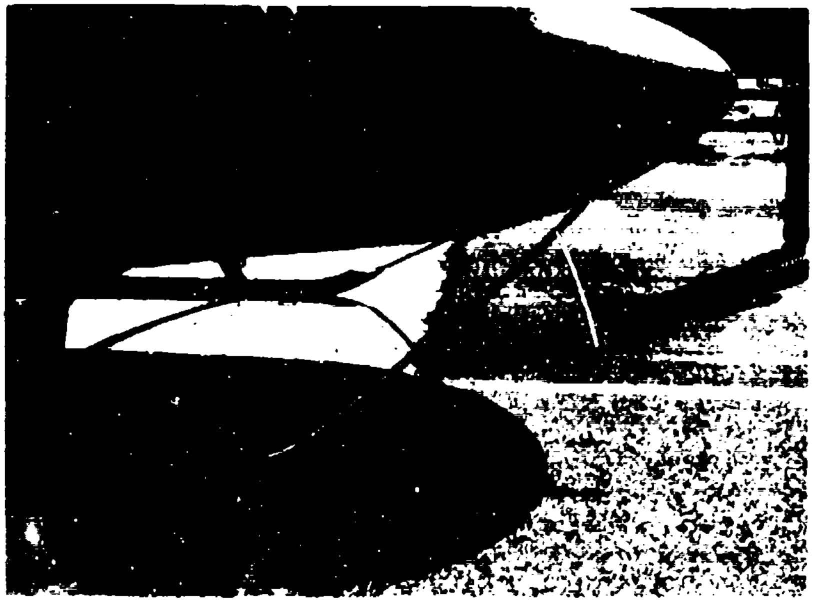

Figure 6. Skid qear deflector, side view.

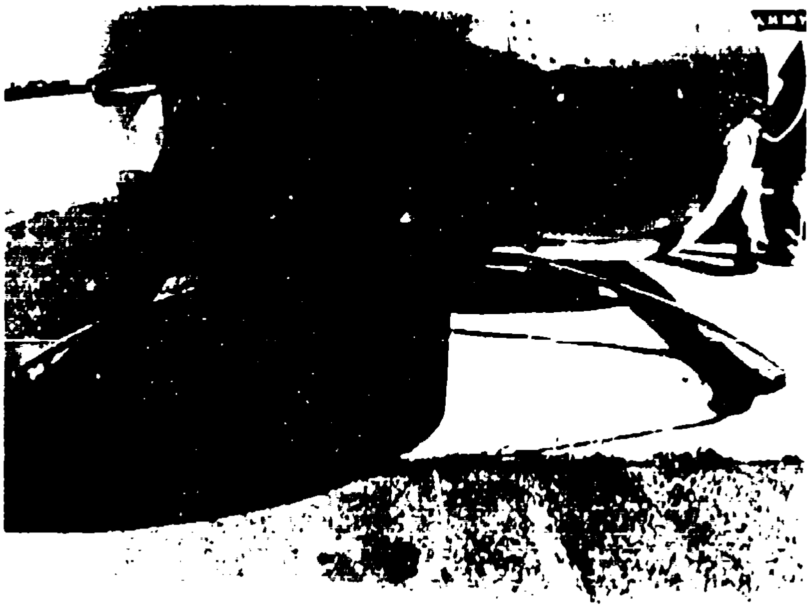

Figure 7 Skid gear deflector, front view.

Figure 8. Tail deflector system.

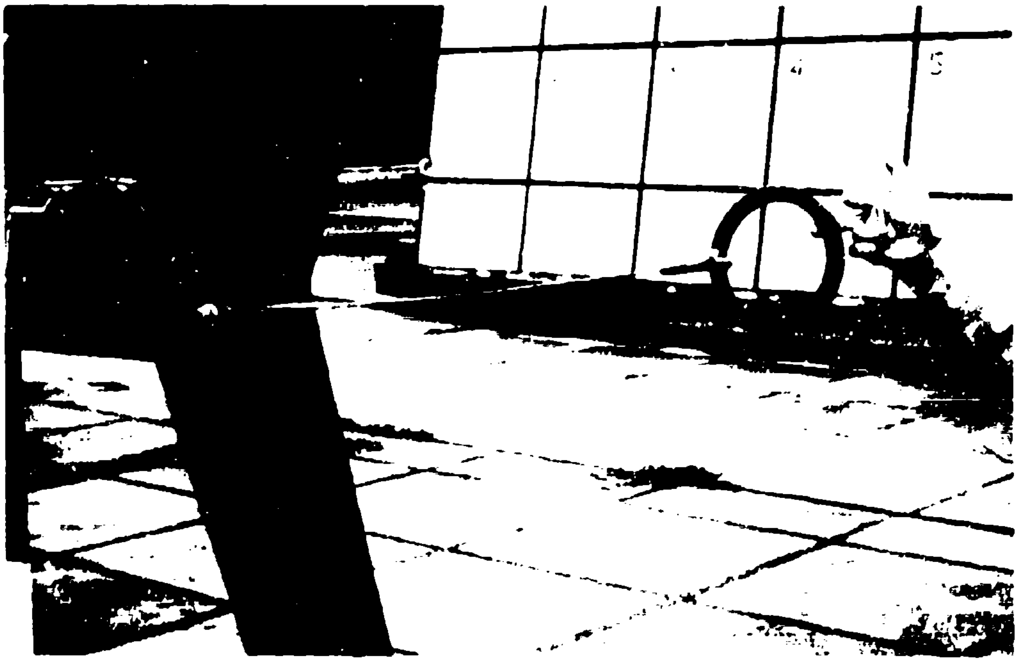

Figure 9. Pullback cable attachment fixture.

Bristol Aerospace Limited had used an objective wire section approximately 10 feet long, supported by a guy cable, for their tests (see Figure 10). Had BAL used normal span wires for each of their 52 wire-cutting tests, the cost would have been prohibitive.

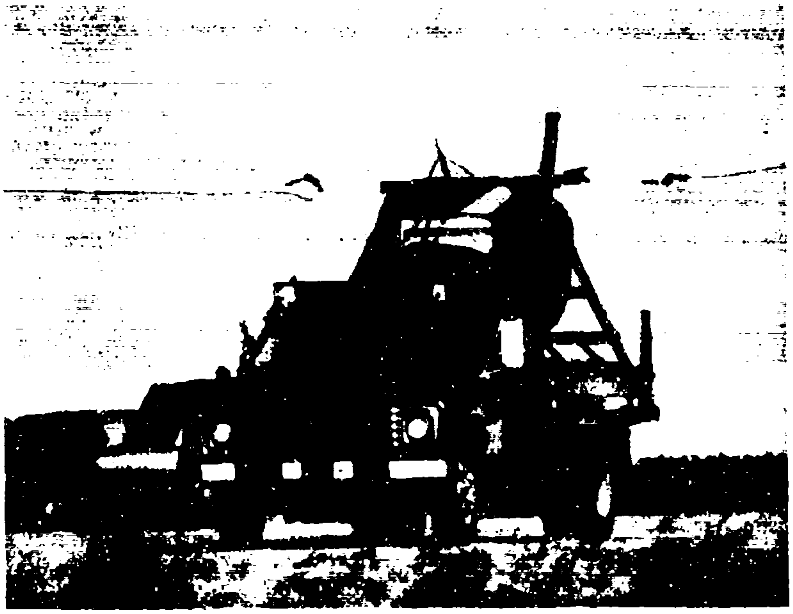

Figure 10. Canadian wire cutting test apparatus.

INSTRUMENTATION

Nine instruments were used to record data during the tests. These included gyros to measure pitch, roll, and yaw attitude and pitch rate; accelerometers to determine the longitudinal, vertical, and lateral loads a pilot would experience during wire impact; and load cells to measure the wire tension increase throughout the deflecting/cutting sequence. The instrumentation and battery package as installed in the rear seat of the test aircraft is shown in Figure 11.

Instrumentation data was conveyed to the ground-based recorder in the instrumentation trailer through an umbilical cable. To minimize the effect of the umbilical cable on test aircraft attitude, the cable was directed up a swing cable, over the gantry, and down to the instrumentation trailer. This necessitated an umbilical cable length of approximately 800 feet.

Two on-board NiCad batteries provided power to the instrumentation circuitry and the instruments. Part of the test countdown sequence included a 10-minute power-on warm-up of the gyros. Appendix A provides a detailed description of the instrumentation used in this test and describes the mounting, calibration, cabling, circuitry, and recording procedures.

Aircraft speed at wire impact was measured by two tripod-mounted radar devices. No attempt was made to include strain gages to measure cutter and supporting structure loads since this was accomplished by Bristol Aerospace Limited over a wide range of conditions.

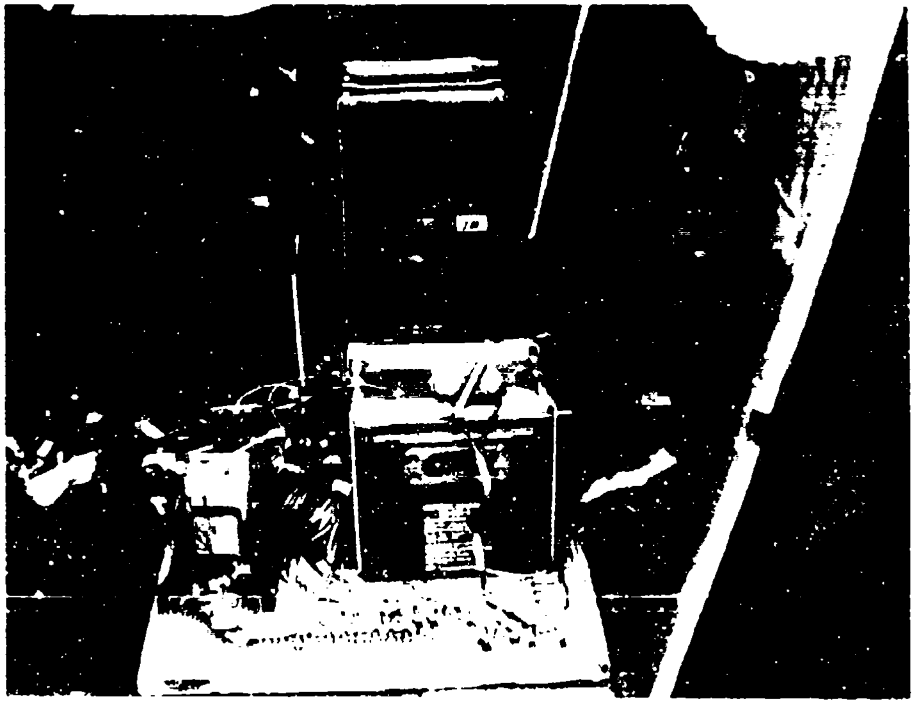

Figure 11. Test instrumentation and battery installation.

PHOTOGRAPHIC COVERAGE

Two photosonic high-speed (650 frames/sec) 16mm motion picture cameras were installed on the test aircraft. One was mounted in the cockpit to provide a pilot's-eye view during the test (Figure 12). The other was mounted to the right skid to allow a view of the lower cutter performance (Figure 13). A 13mm wide-angle lens was used because of its wide field of view and its ability to obtain visual data at close range. These cameras were powered by an on-board NiCad battery and were activated by a signal from the ground control room at the T minus 2 seconds point of the aircraft release countdown.

The exterior motion picture photography was provided by NASA except for hand-held cameras operated by ATL photographers. Ground coverage included five high-speed (650 frames/sec) ground cameras and two 70mm still sequence (50 frames/sec) cameras.

Figure 12. Cockpit camera installation.

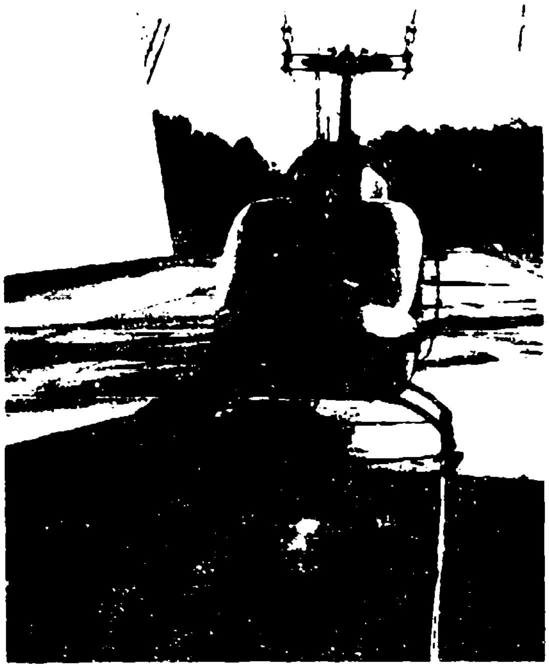

Figure 13. Skid gear camera installation.

TEST DESCRIPTION

For each test, the OH-58A was lifted by the two swing cables to a height that would provide the desired location of initial wire impact. The cables were locked, as shown in Figure 14. For the upper cutter tests the desired wire impact location was slightly below the middle of the windshield centerpost. For the lower cutter tests the desired wire impact point was in the area of the landing light. Figure 14 also shows that the swing cables were attached to the rotor hub by means of a ring attachment that would allow movement of the aircraft independent of the swing cables. The aircraft was then drawn back by the pullback cable until the aircraft was in a position similar to that shown in Figure 15. The height was calculated to provide a pendulum swing flight path that would result in the planned wire impact conditions listed in Table 1. The 40-knot impact speed was selected as representative of terrain flight operations. Although airspeed at impact could have been varied, the short time of facility availability coupled with the time and cost of wire erection precluded additional testing. The test schedule is shown in Table 2.

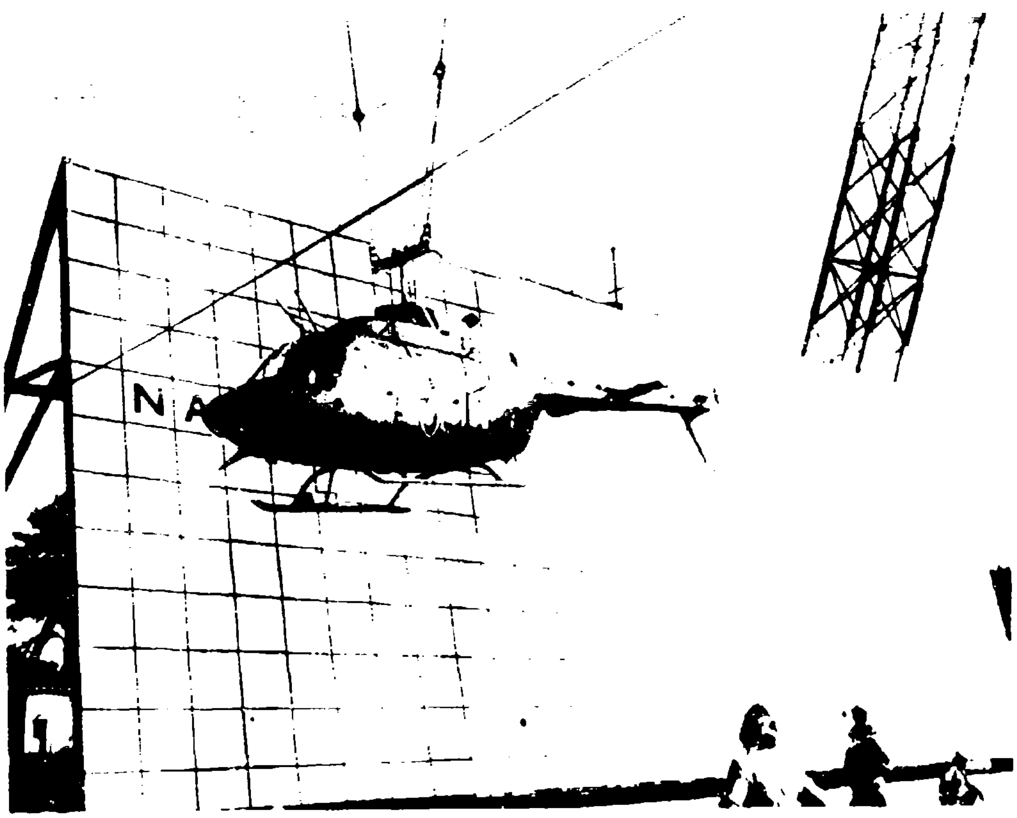

Figure 14. Pre-pullback position.

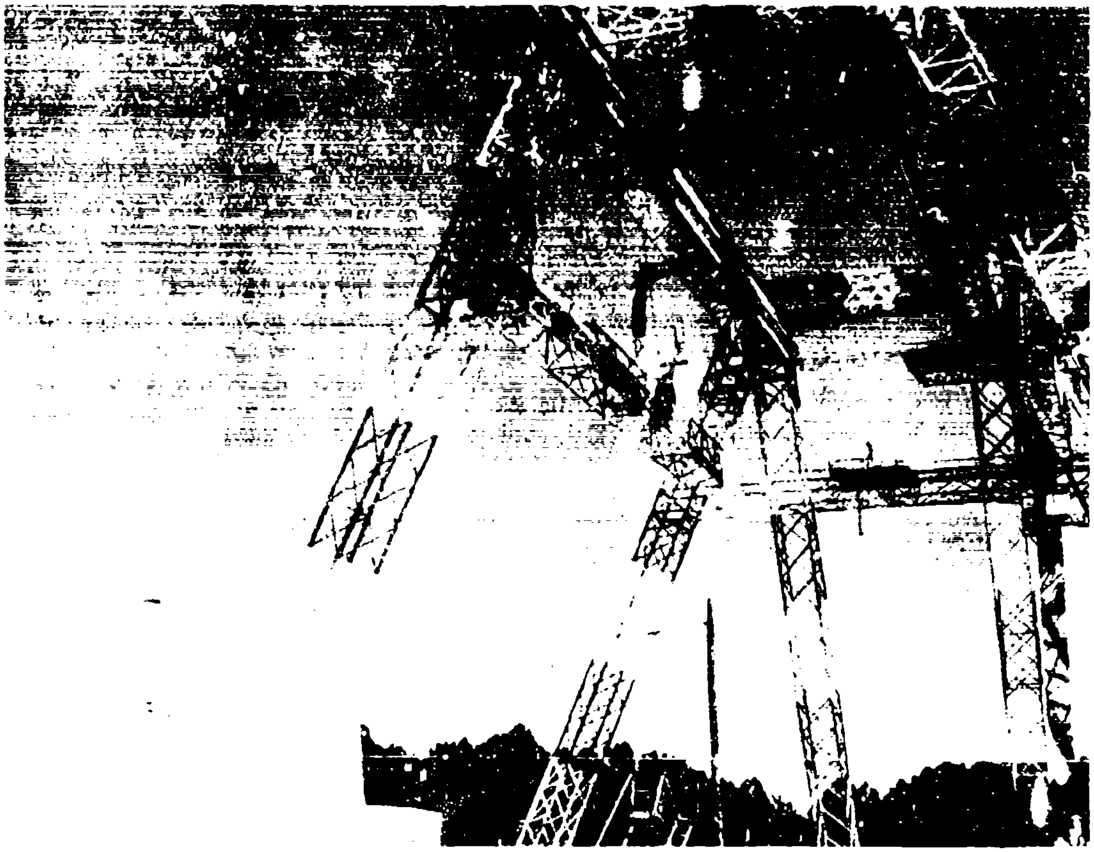

Figure 15. Pullback position.

TABLE 1. AIRCRAFT CONDITIONS AT WIRE IMPACT

	Planned	Actual
Airspeed, kn	40	37
Pitch angle, deg	0	(See note)*
Yaw angle, deg	0	−15
Roll angle, deg	0	0

*Note: Varied between +2 and +19 degrees because of swing dynamics and wire impact at different locations on the aircraft.

TABLE 2. PENDULUM SWING TEST SCHEDULE

Test Number	Test	Date	Objective Wire
1	Stability check swing	28 Sep 79	None
2	Stability check swing	28 Sep 79	None
3	Upper cutter	1 Oct 79	10M cable supporting a 50-pair commo cable
4	Upper cutter	3 Oct 79	10M cable supporting a 50-pair commo cable
5	Lower cutter	3 Oct 79	10M cable supporting a 50-pair commo cable
6	Skid gear deflector	4 Oct 79	10M cable supporting a 50-pair commo cable
7	Multiple wires	5 Oct 79	Two 0.419-inch-diameter high-power transmission cables and one 10M cable supporting a 50-pair commo cable.

TEST RESULTS

WIRE STRIKE PROTECTION SYSTEM (WSPS) EXPERIMENT

Tests 1 and 2

Tests 1 and 2 were conducted without wires erected to ascertain the aircraft motion during a pendulum swing while supported only through the rotor mast. Neither of these tests resulted in erratic flight motions, indicating that no further restraint of the aircraft during the wire impact tests was required. During these stability check swing tests and subsequent tests the aircraft yawed left 15 degrees and maintained that attitude throughout a large segment of the swing arc including the wire impact point. This was attributed to the basic aerodynamics of the airframe in free flight. The actual wire impact conditions are also shown in Table 1. The lower airspeed than that planned was attributed to the fact that drag was not properly considered in the pretest calculation. The positive pitch angle occurred because the aircraft was on the upswing portion of the pendulum arc with a nose-up attitude when it impacted the wire.

Tests 3 and 4

In each test the objective wire impacted the aircraft slightly above the middle of the windshield centerpost, was deflected into the upper cutter, and was severed. Since the 10M cable is steel it was not significantly weakened by the sawtooth cutter insert in the centerpost deflector. In fact, the wire impact resulted in breaking a number of teeth off of this cutter. The upper cutter performed as designed, notching the cable so as to result in ease of failure in tension. The broken 10M cable and supported 50-pair communications cable are shown in Figure 16. After twice cutting a 10M steel cable, the upper cutter blade showed only minor scoring and paint removal, as shown in Figure 17. Because the aircraft was yawed left 15 degrees at wire impact, the steel cable contacted the right windshield, resulting in minor scratches as shown in Figure 18.

Figure 16. Objective wire and communications cable after being severed.

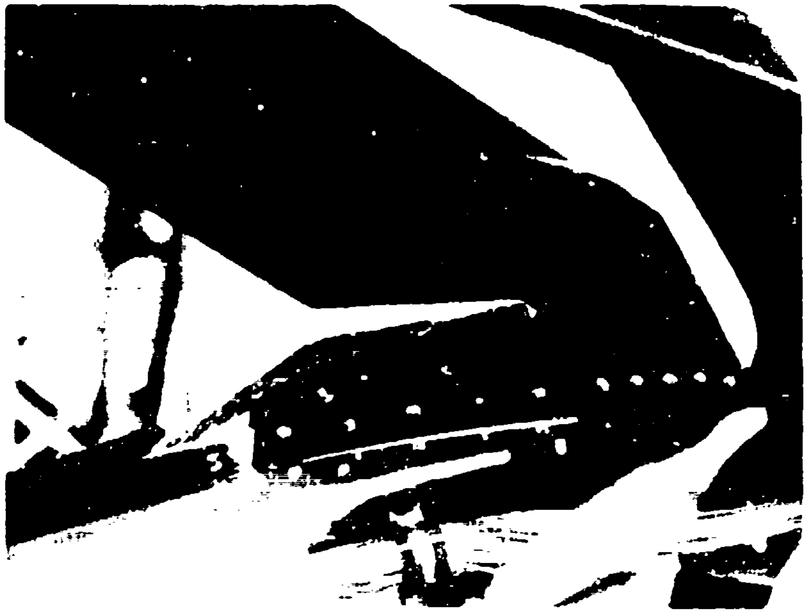

Figure 17. Post-test upper cutter condition.

Figure 18. Windshield scratches from cable impact.

Recorded longitudinal and lateral forces are presented in Figures 19 and 20 respectively and are insignificant considering pulse magnitude and duration; these forces would not adversely affect crew performance. In viewing the data the reader must take into account the aircraft oscillations inherent in a pendulum swing, the dynamic interface of the helicopter with the swing cables and attachment rings, and the wire impact/deflection/cutting time sequence. The latter factor entails initial impact of the wire with the aircraft, deflection to the cutter, impact with the cutter, and the cut, with the wire stretching and tensioning throughout this sequence. The pitch-change time history was also insignificant because the wire impact was near the vertical cg of the aircraft. Figure 21 depicts this parameter for the pendulum swing, which by its nature will result in a continuous change in aircraft pitch attitude.

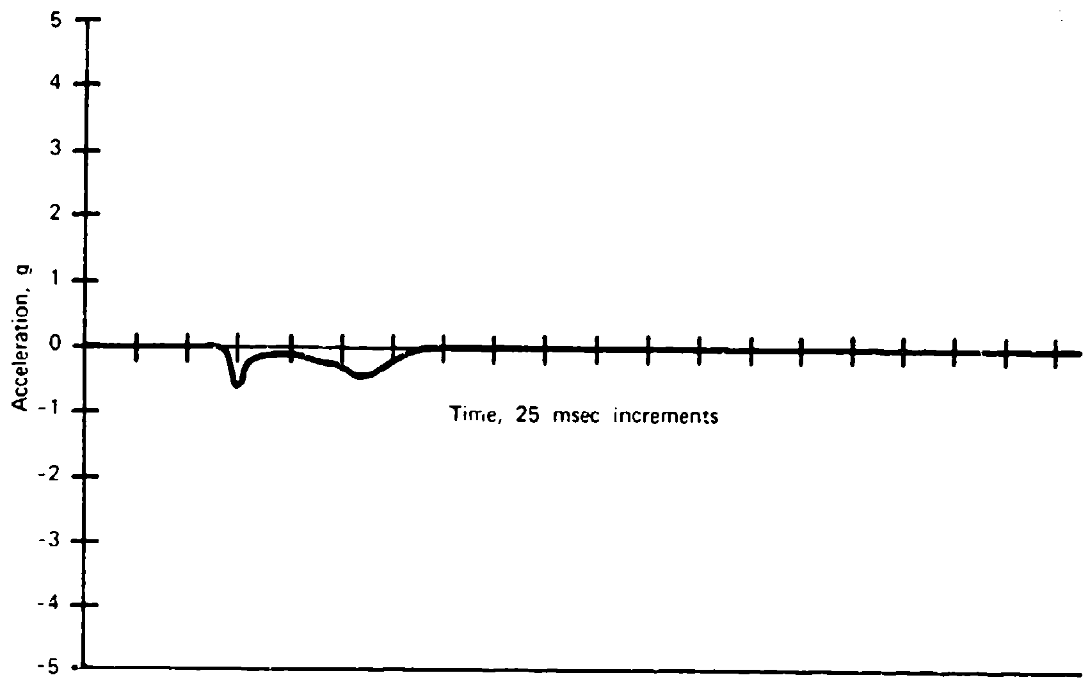

Figure 19. Test 4 longitudinal impact forces.

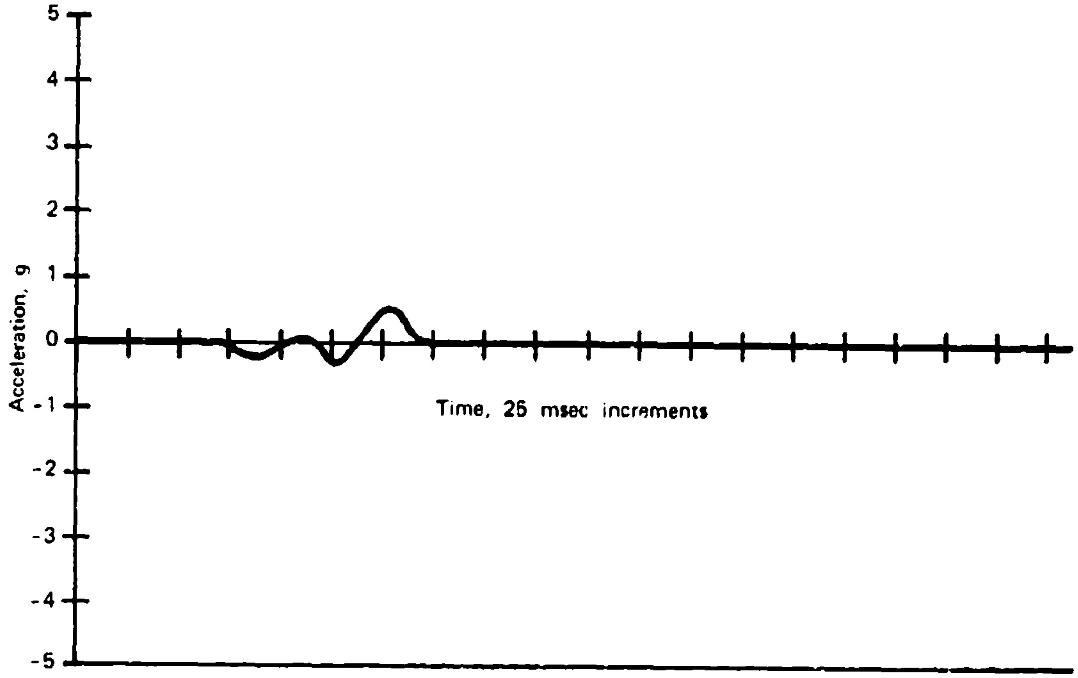

Figure 20. Test 4 lateral impact forces.

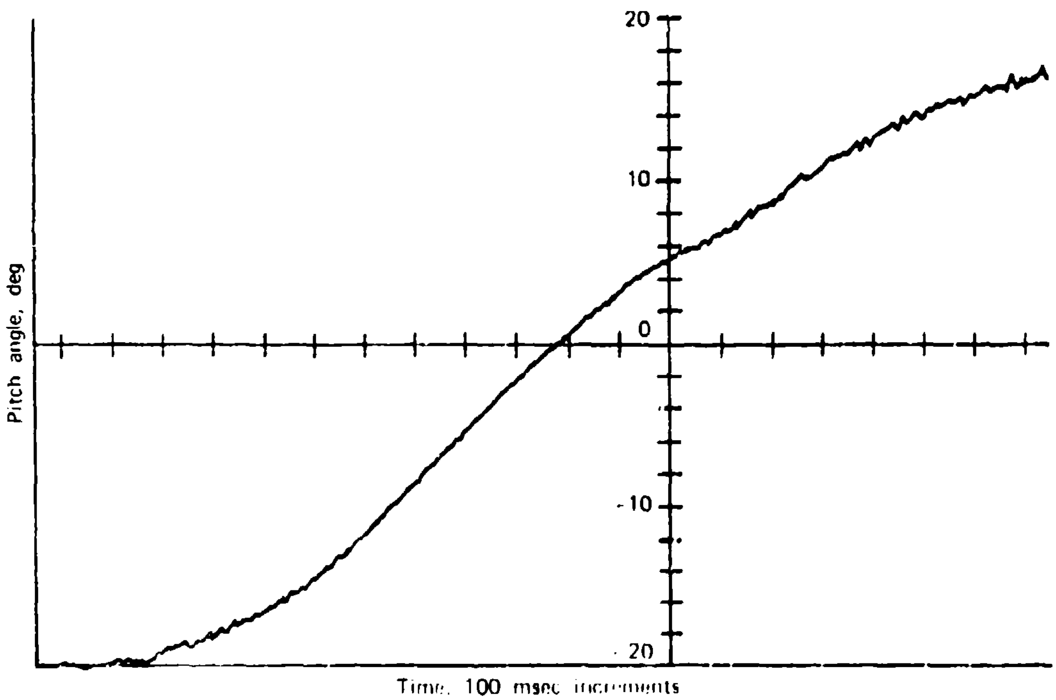

Figure 21. Test 4 pitch attitude change

Test 5

The objective wire impacted the aircraft below the pitot tube in the landing light area, causing minor damage to the Plexiglas cover (see Figure 22), then deflected into the lower cutter and was successfully severed. Figures 23 and 24 are still sequence photos of this test. This was the first time the lower cutter had been tested; the Canadian test setup precluded testing of this WSPS component.

Because of the location of the lower cutter with respect to the aircraft vertical cg, the nose-down pitching moment should be the greatest attitude change encountered in a test of this nature. As can be seen in Figure 25, the nose-down pitch variation was slight and would be easily controllable by the pilot. Figures 26 and 27 show the recorded longitudinal and lateral impact forces, respectively. They also were of such a short pulse as to be insignificant with respect to crew performance effect. The average peak wire tensiometer reading for Tests 3 through 5 was 1368 pounds. This was consistent with the Canadian test results.

Figure 22. Test 5 wire impact damage to aircraft.

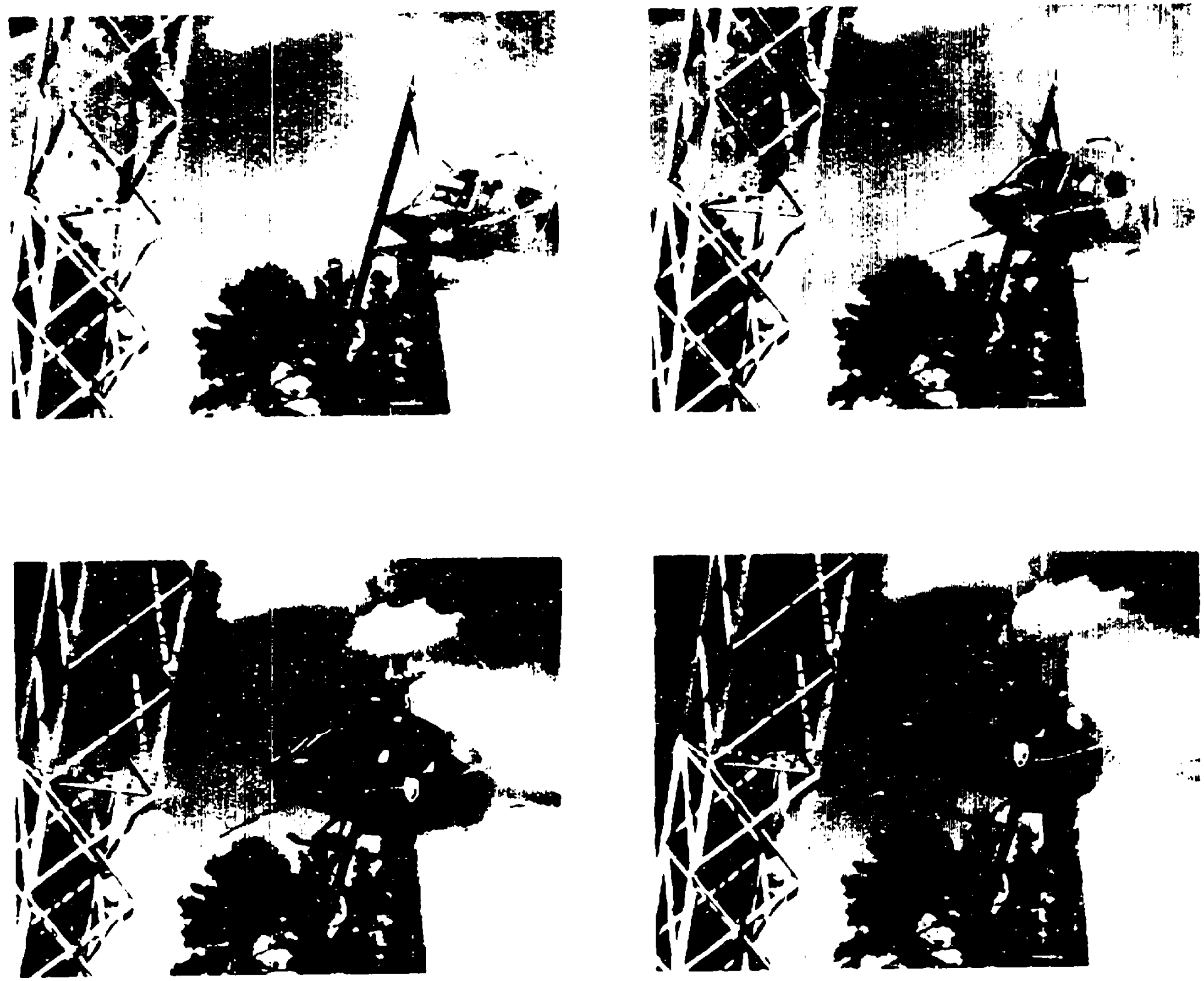

Figure 23. Side view of lower cutter performance.

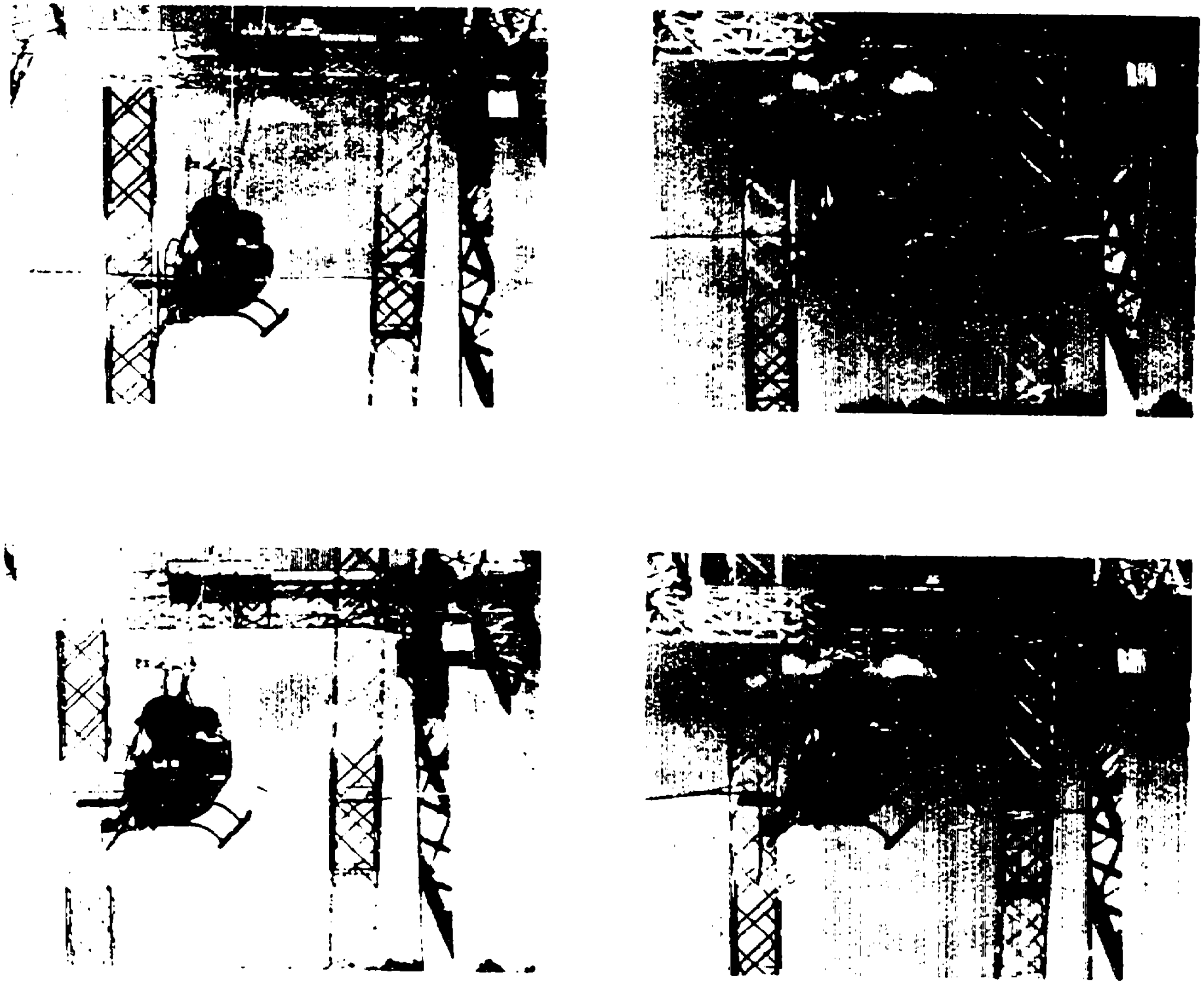

Figure 24. Front view of lower cutter performance.

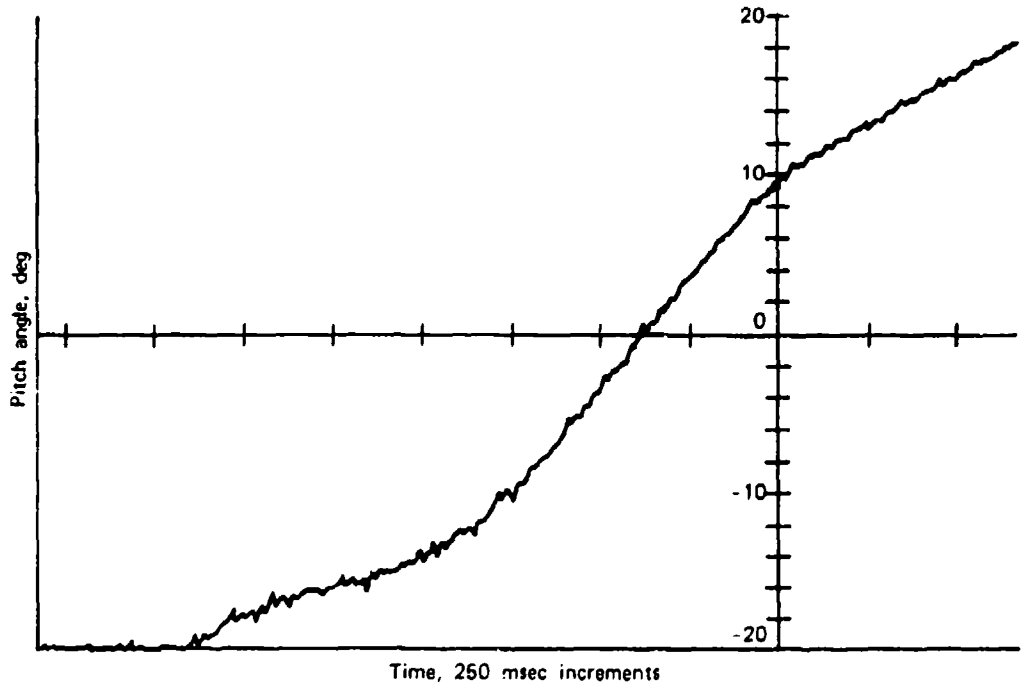

Figure 25. Test 5 pitch attitude change.

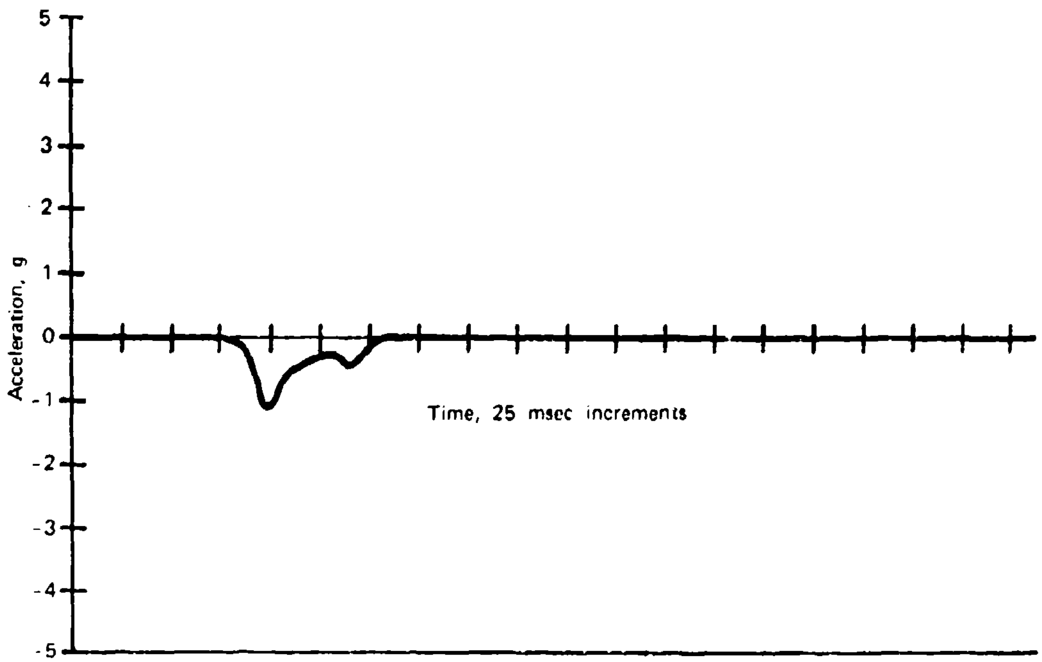

Figure 26. Test 5 longitudinal impact forces.

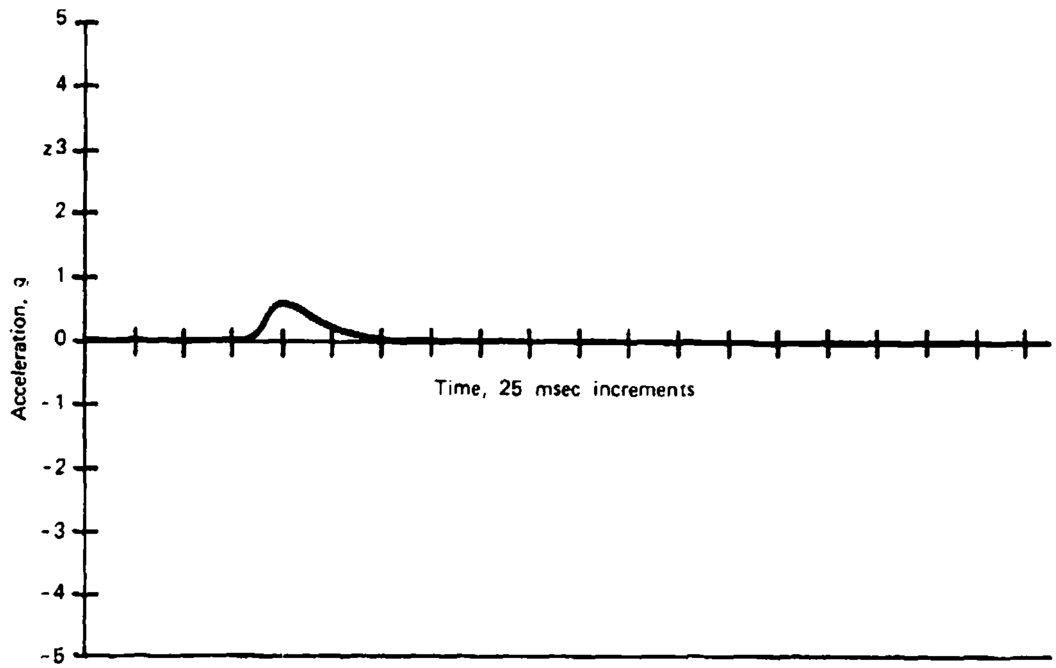

Figure 27. Test 5 lateral impact forces.

Test 7

This test used two 0.419-inch-diameter power transmission cables and one 10M cable supporting a 50-pair commo cable as the objective wires. Since multiple wires are involved in many helicopter wire strike accidents, this test was of great value. The objective wires are depicted in Figures 28 and 29. Arrangement and spacing of the cables were in accordance with standard installation procedures when there is a mix of power transmission and communication lines supported by the same poles.

Weather conditions for this test were poor with rain resulting in the inability to use most of the ground movie cameras and both of the 70mm still sequence cameras. However, this was the last day of facility availability and the test was accomplished during a short break in the rain shower activity. The test was a complete success, as depicted by the photo series in Figure 30. The two copper high-voltage power transmission cables impacted the windshield centerpost and deflected upward to the cutter. One of these cables was cut by the sawtooth cutter inserted in the deflector. The other was weakened by this cutting edge and was finally severed in the upper cutter. The 10M steel cable with the supported 50-pair communication cables was deflected into the lower cutter and easily severed. It should be noted that after two cuts (Tests 5 and 7) the lower cutter showed no signs of scoring and only had some paint removed from it. With a multiple wire strike, the deceleration forces were expected to be greater than that of a single wire strike. This was the case, as shown in Figures 31 and 32, which depict the longitudinal and lateral forces respectively. For a longitudinal force peak of less than 2 g or an average of less than 1 g, over a pulse period of less than 50 milliseconds a pilot would feel only a force equivalent of a light gust load. The lateral deceleration spike of 1 g corresponds with impact of the deflected cable into the cutter. Since this pulse has only a 25-millisecond duration, it is insignificant. The pitch attitude time history is shown in Figure 33 and was again analyzed as easily controllable and therefore insignificant.

The potential effect on OH-58 blade flapping of wire impact loads was analyzed using the Rotorcraft Flight Simulation Computer Model. This model, developed at Bell Helicopter Textron, is used extensively for handling qualities analyses and is considered valid for rotor blade flapping definition. In applying the impact load and pitch change data obtained from Test 7 to the computer model, the change in linear and angular rates of the fuselage was so small that there was no noticeable effect on rotor blade flapping relative to the fuselage.

Figure 28. Description of multiple cables for Test 7.

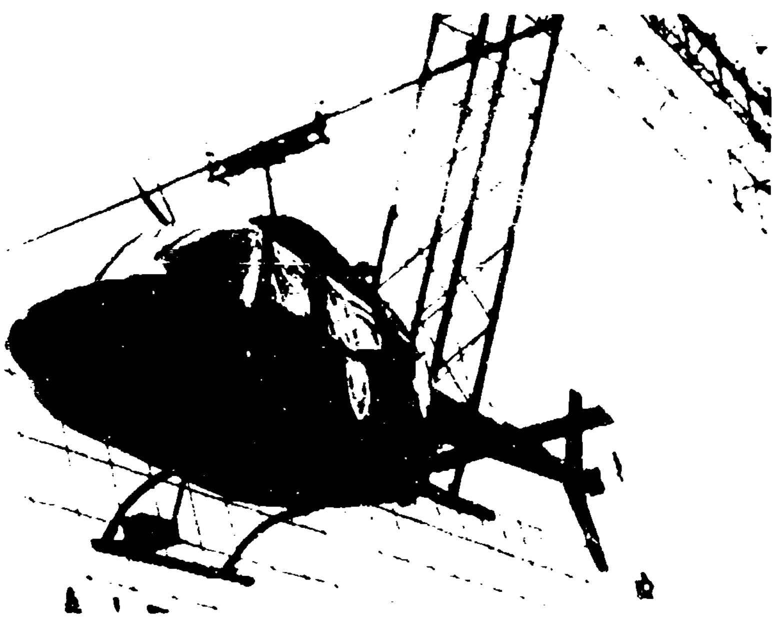

Figure 29. Test 7 multiple wires as erected.

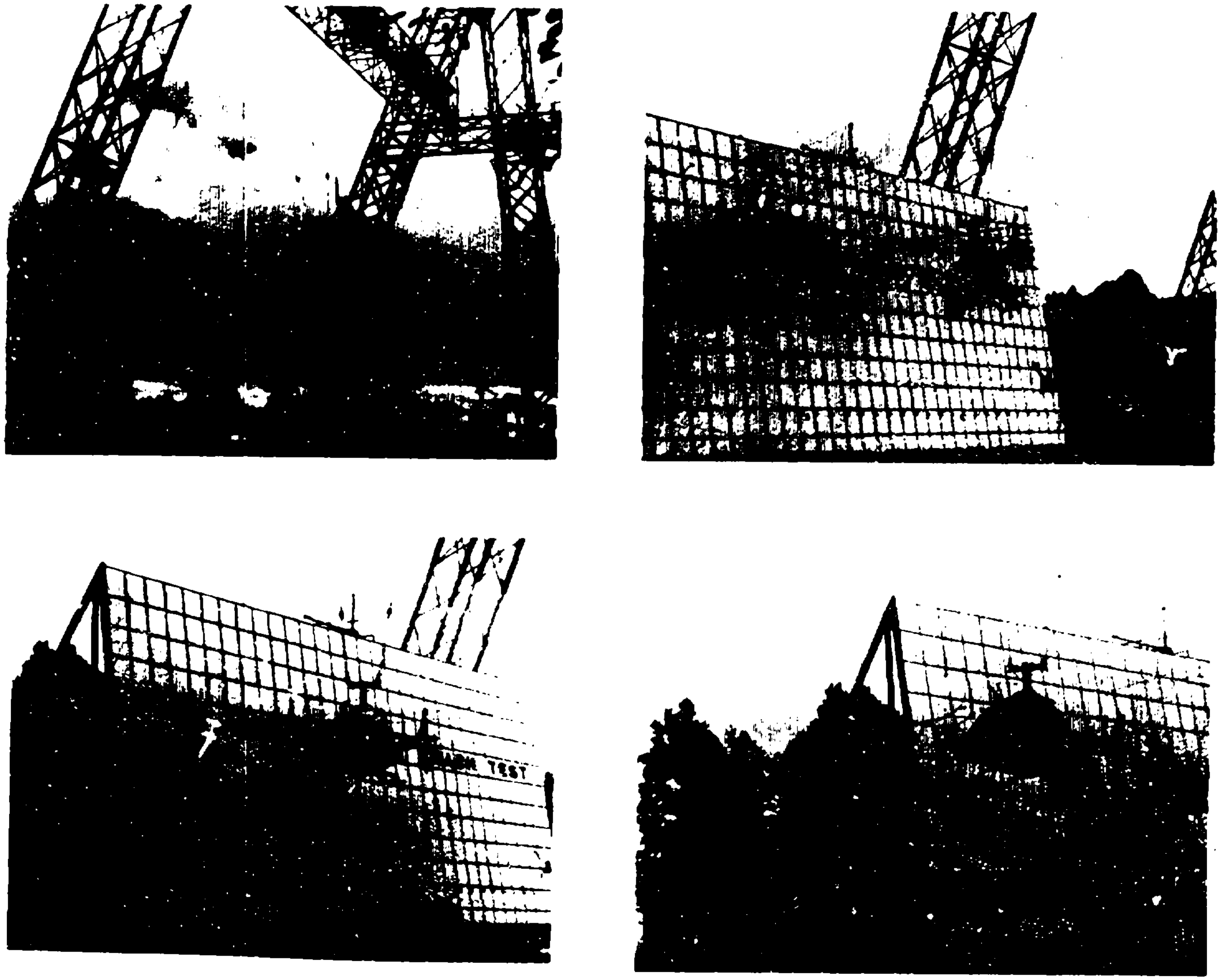

Figure 30. Multiple wire test sequence.

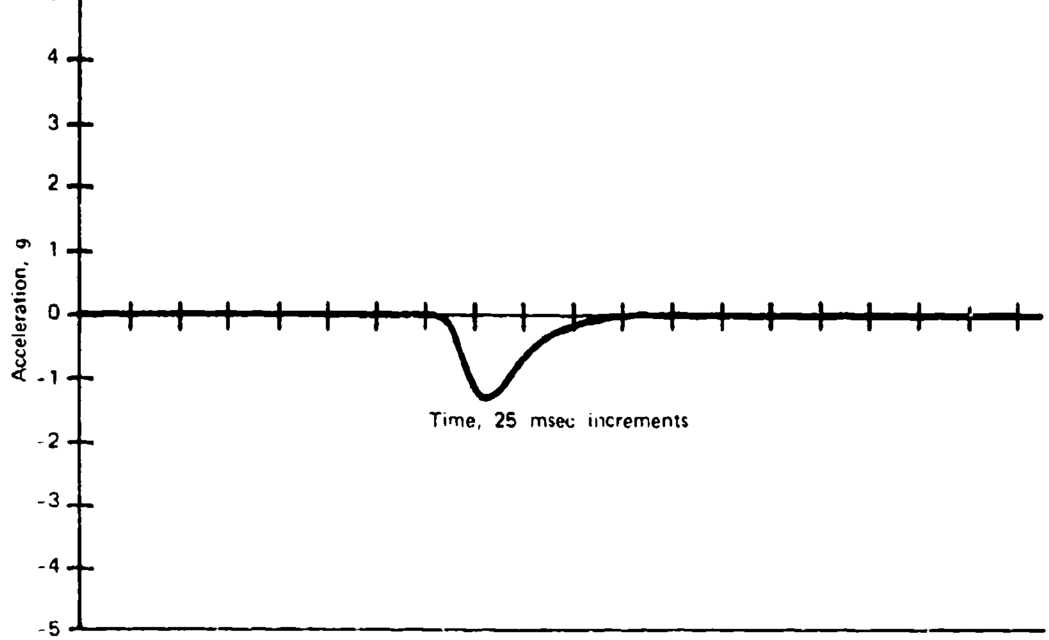

Figure 31. Test 7 longitudinal impact forces

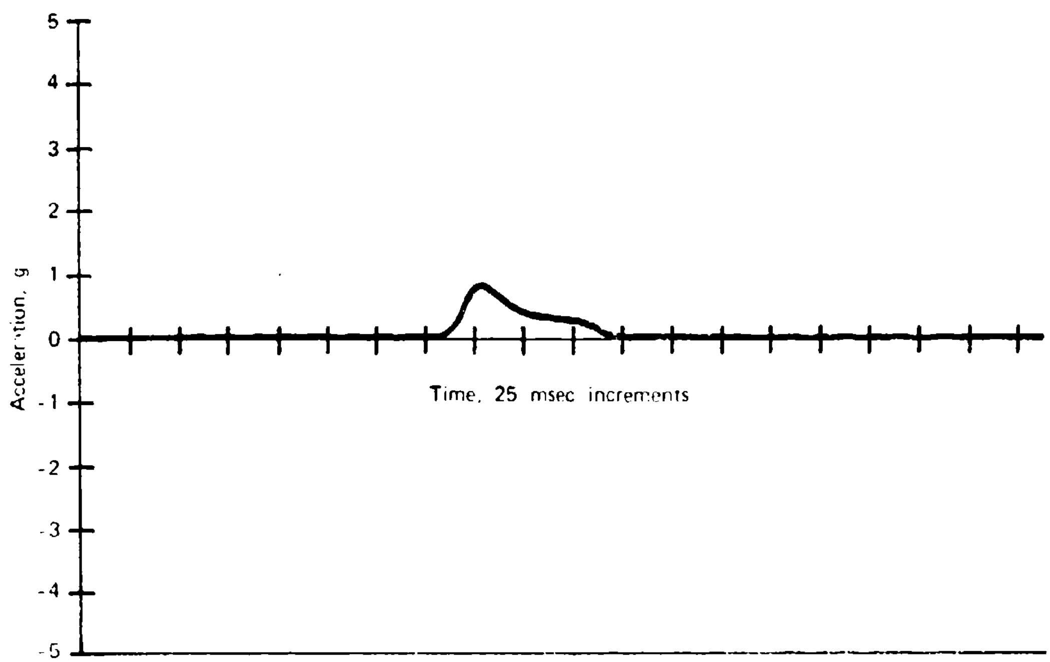

Figure 32. Test 7 lateral impact forces.

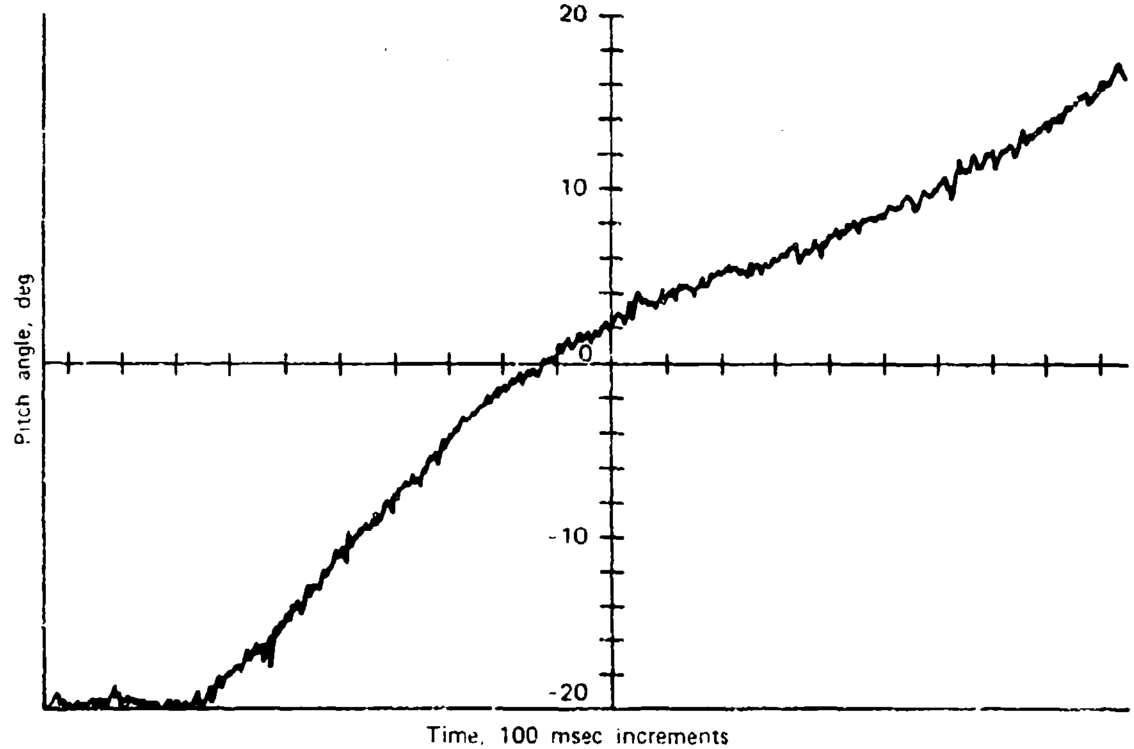

Figure 33. Test 7 pitch attitude change.

SKID GEAR WIRE DEFLECTOR EXPERIMENT

Test 6

The Test 6 conditions represented some of the most severe that could be expected in actual operation:

1. Because of the 15-degree aircraft yaw, one side of the deflector had to take the entire load.

2. Just past the bottom of the pendulum swing the aircraft has a centrifugal force acting on it, thus increasing its effective weight. In addition, the requirement for the aircraft to ride up and over the cable creates an upward acceleration, resulting in additional g forces. These factors are additive in increasing the force of the wire on the deflector.

3. The nose-up attitude at wire impact resulted in an increased deflection angle, which increases the normal force vector of the wire in the deflector.

Figure 34 shows the wire impact sequence. As can be seen, the right side of the deflector was subjected to the entire impact load and bent inward, snagging the wire and preventing deflection. The right skid was broken and the wire became caught on the forward skid gear cross tube. The resulting forces were such that the left line pole supporting the cable was broken at ground level and thrown approximately 170 feet to a position forward and to the right of the aircraft (Figure 35). The right pole was left leaning with guy fixtures pulled from the ground. This can be seen in the background of Figure 36. The 10M messenger and 50 pair communications cable were not damaged. The skid gear deflector was thrown to the apron (see Figure 37).

The data collected is meaningful only in that it indicates impact forces when the wire is not cut. Figure 38 depicts the longitudinal forces experienced during the impact sequence. Force magnitude and duration are such that they would adversely affect crew performance in controlling the aircraft. Had the aircraft not been restrained by the swing cables it is believed that it would have pitched over into the ground, as has been the case in a number of Army helicopter accidents. As a result of these tests, an alternate skid gear deflector was designed that may have adequate strength. It consists simply of slip-over extensions of the skid gear without attachments to the fuselage. However, this concept would add 55 pounds to the aircraft and is therefore not considered practical. In addition, the effects of a deflected cable on the aft end of the aircraft and on aircraft control remain unknown potential problems.

Figure 34. Wire impact sequence during test.

Figure 35. Left line pole after test.

Figure 36. Right line pole after test.

CONCLUSIONS

1. The passive WSPS concept tested proved to be highly effective in protecting the OH-58 helicopter against mishaps caused by wire strikes. When installed fleetwide, the system should result in fewer accidents, injuries, and fatalities than are presently being experienced in unprotected Army helicopters.

2. As a result of the data obtained from these tests and the tests conducted by BAL, it can be assumed from the ease of cutting the objective wires that the WSPS has the capability to deflect and cut wires and cables of greater diameter and strength than the design objective wire.

3. The wire impact/deflection/cutting sequence does not have a significant effect on the helicopter or the operator with respect to performance, control, and blade flapping.

4. A skid gear deflector is not a practical OH-58 retrofit from a cost or weight standpoint.

5. To be competitive with a WSPS lower cutter a skid gear deflector would have to be designed into an aircraft at the inception of the program. Such a design must also include protection of aft components once a wire is deflected past the skid gear.

6. The WSPS lower cutter is probably more suitable wire protection than a deflector for wheeled helicopters.

RECOMMENDATIONS

Based on the ATL wire strike protection test series, it is recommended that:

1. The Army initiate retrofit of OH-58A helicopters with the WSPS tested, and that a program be initiated to configure this concept for UH-1, OH-58C, and AH-1 applications with the intent of subsequent retrofit of those helicopters.
2. All new helicopter specifications include design criteria and a requirement for a WSPS.
3. The BLACK HAWK and Advanced Attack Helicopter Project Managers take action to: define a WSPS configuration suitable for these helicopters; retrofit aircraft already produced; plan for WSPS installation during production.
4. Any consideration of a skid gear deflector for future aircraft systems include a comparative analysis with a cutter considering cost, weight, and effectiveness.

APPENDIX A
INSTRUMENTATION

GENERAL

Static and dynamic test parameters were obtained using three basic type transducers: load cells, pitch/roll gyros, and accelerometers.

Transducers located on the test aircraft were secured to a mounting board positioned and fastened to the seat behind the pilot's seat. All transducers were connected to remote recording equipment through multi-pair signal cable. A Genisco Model 10-276 magnetic tape recorder received the signal inputs via an 800-foot umbilical line running from the aircraft, up the swing cable, over the gantry, and to the instrumentation trailer located 225 feet from test impact point. This trailer contained all necessary signal-conditioning, instrumentation power, and accessory units other than the required on-board test aircraft transducer power supply.

ATL instrumentation technicians designed, fabricated, and wired the circuitry. They performed laboratory checkout, instrumentation system installation in test aircraft, recording system setup, and the makeup of the signal cable system for data collection.

APPLIED TECHNOLOGY LABORATORY RECORDING SYSTEM

The data recording system block diagram is presented in Figure A-1. Data obtained from transducers on board the test aircraft were recorded via signal cables to a magnetic tape system.

TRANSDUCER CHANNEL CIRCUITS

Accelerometers

A triaxial accelerometer, CEC Model 4-204-001 (± 10g), was used to acquire aircraft cockpit area acceleration forces during the pendulum swing of the aircraft and during the wire impact/deflection/cutting sequence. Longitudinal, lateral, and vertical acceleration data were acquired.

Load Cells

Two load cells, Baldwin-Lima-Hamilton type SR-4, 10,000-lb capacity, were used to detect wire tensioning forces encountered during contact of the aircraft with the suspended cable. Load cells were mounted at each end of the 160-foot objective cable placed transversely to the test aircraft travel path.

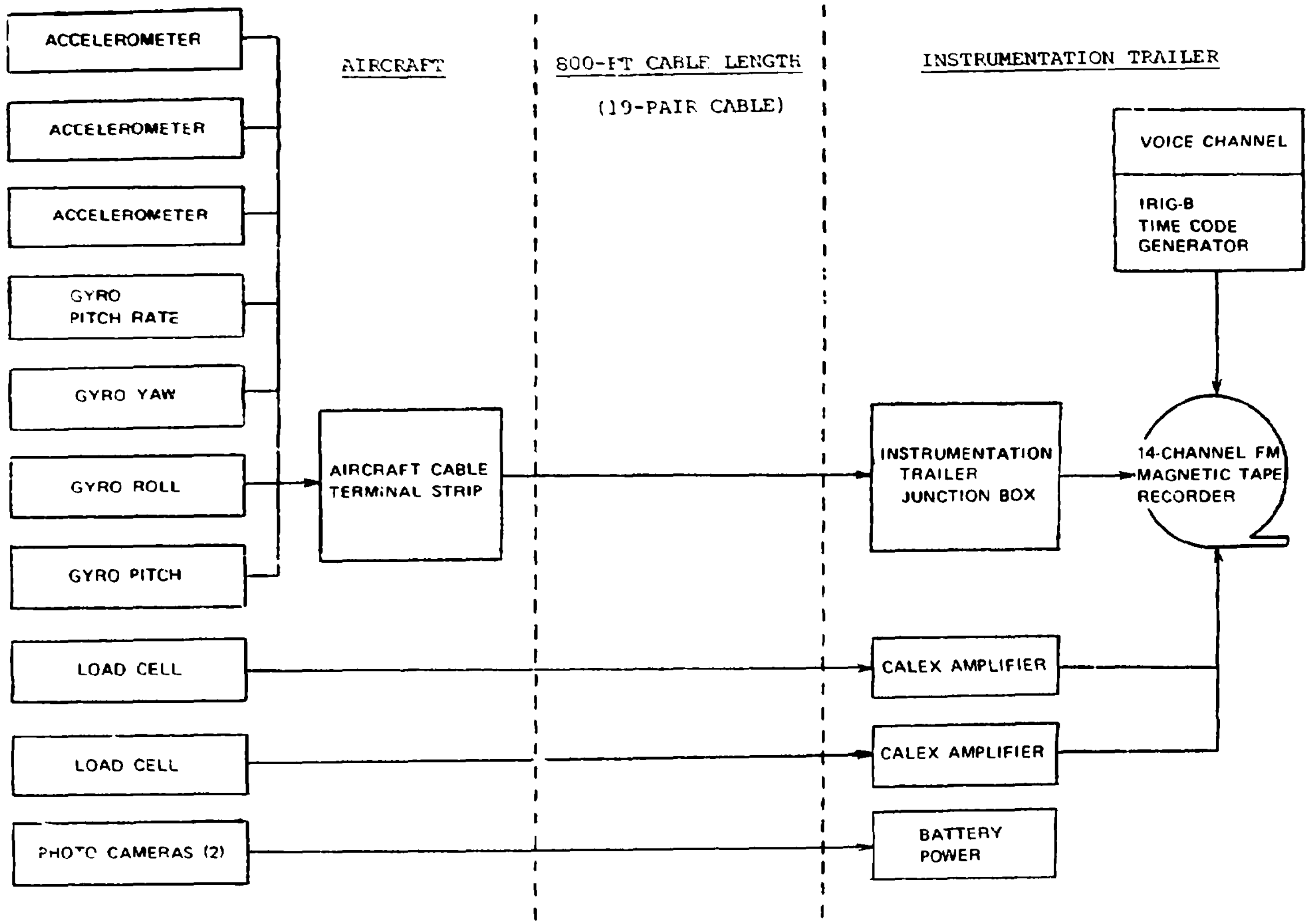

Figure A-1. Recording system block diagram.

Gyros

Gyros were used to detect roll, pitch, yaw, and pitch rate of the test aircraft during the complete pendulum swing arc, to include start position, wire impact, and finish position. The pitch channel used a Humphrey ±60°/sec gyro, Model CF 18-0402-I. All other gyro parameter channels were detected via Minneapolis-Honeywell JG 7044A-4 vertical gyros mounted for specific plane measurement.

Calibration

The load cell transducers and the triaxial accelerometer were calibrated by the ATL calibration facility prior to the field test. Calibration of gyro channel circuits was accomplished prior to each test. Post-test static calibrations were also completed for the accelerometer and gyro channels. Load cell calibrations were performed at the test site, consisting of circuit zeroing and a shunt-valve step.

Data Channels

Table A-1 lists recorder channels and functions.

Data Playback

The data playback system is graphically shown in block diagram form in Figure A-2. This system provides data analysis of test information and hard-copy print graphs of finalized data.

TABLE A-1. RECORDER FUNCTIONS

Data Channel Number	Recorder Track Number	Transducer	Measurement
1	1	Accelerometer ± 10g	Longitudinal acceleration
2	2	Accelerometer ± 10g	Vertical acceleration
3	3	Accelerometer ± 10g	Transverse acceleration
4	4	Gyro	Pitch rate
5	5	Gyro	Yaw
6	6	Gyro	Roll
7	7	Gyro	Pitch
8	8	Load cell, 10,000 lb	"A" tension
9	9	Load cell, 10,000 lb	"B" tension
10	10*		
11	11*		
12	12*		
13	13	Voice channel	
14	14	Irig clock	Irig-B time

*Channel 10 unused. Channels 11 and 12 shorted for reference.

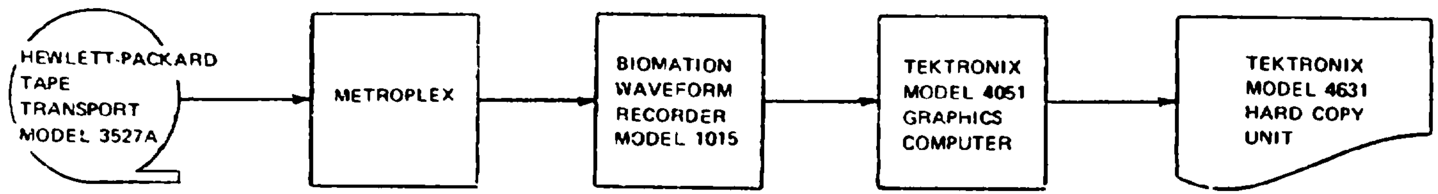

Figure A-2. Data playback system block diagram.